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AUXILIARY ELECTRODE INSTRUMENTATION FOR NICKEL CADMIUM CELLS

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KENNETH O. SIZEMORE

THOMAS J. HENNIGAN

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GODDARD SPACE FLIGHT CENTER

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Kenneth O. Sizemore and Thomas J. Hennigan
National Aeronautics and Space Administration

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Abstract 24928

This paper describes the use of an all-solid-state battery charge control system for nickel cadmium cells which employs auxiliary electrodes and a reconditioner to discharge all cells down to zero volt, in order to restore capacity lost by the "memory effect."

The nickel cadmium battery is charged at a constant potential level of 1.46 volts per cell (at 25^{o} C) by a shunt regulator until the threshold voltage of an auxiliary electrode is reached, indicating full charge. At this condition the auxiliary electrode signal can be used either to reduce the regulating level of the shunt regulator to a lower voltage level, or to control the conductance of a series transistor so that the battery is trickle-charged at a constant-current rate.

Each cell of the battery contains an auxiliary electrode, which is capable of controlling the charge of the battery. Recent tests show that the electrode which first reaches the threshold level during early cycling continues to be the controlling electrode throughout the life of the battery. This suggests that it is not necessary to have a sensor on every cell.

Author

*Speaker

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AUXILIARY ELECTRODE INSTRUMENTATION

INTRODUCTION

For long life and reliability, nickel-cadmium cells are the best rechargeable electrochemical devices to be used to complement solar arrays in storage of electrical energy for many spacecraft. They offer the advantages of relatively insoluble electrodes in potassium hydroxide electrolyte, high rate charge and discharge, and at moderate depths of discharge they have a life expectancy exceeding two years. In order to prolong their life and insure high reliability, means must be provided to carefully control the charge of the cells to prevent excessive pressure buildup and minimize heat generation during overcharge.

In spacecraft that have moderate power requirements and in which energy stored by the cells can be replaced at charge rates of C/10 or lower, few problems are encountered since these rates are within the gas recombination capability of most nickel-cadmium cells. However, to utilize the full capabilities of nickel-cadmium cells by trying to achieve higher depths of discharge which consequently require high recharge rates for near earth orbiting spacecrafts, a precision charge control system must be employed. Unfortunately, the employment of cell voltage sensing in controlling the charge of cells cannot be used with a great deal of precision because the voltage change between normal charge and overcharge is too small to be reproducible over a wide range of operating conditions.

Auxiliary electrodes offer the possibility of precision charge control. In effect they sense the oxygen gas liberated towards the end of charge by the nickel electrodes of a cell. The reduction of oxygen by the auxiliary electrode may be used as a current, voltage, or power source (versus the cadmium electrode) to provide a signal to terminate, or reduce to safe limits, the charge current.

The subject of this paper is the use of the auxiliary electrode and related charge control instrumentation for regulating the charge to the battery. The auxiliary electrode discussed in this paper for charge control is the adsorption hydrogen electrode because of its stability and nearly linear response as a function of oxygen pressure (1).

FUNCTIONAL EXPLANATION OF SERIES CONTROLLER

One of the early charge control systems employed at GSFC and N.A.D., Crane in evaluating and testing of auxiliary electrodes is shown in Figure 1. This system is designed to monitor the auxiliary electrode potential of each cell of a five cell series battery and reduce or terminate charging current when the auxiliary electrode signal of any one of the cells reaches a pre-selected threshold voltage.

This circuit allows a full-charge current to the cells when they are fully or partially discharged since under these conditions the oxygen pressure in the cell is low and consequently the auxiliary electrode signal should be below the threshold voltage. As the cells approach full charge the auxiliary electrode of the low capacity or less efficient cell approaches the threshold level with subsequent limiting of the conductance of the series current control transistor when this level is reached. The diode shunted across the transistor is provided to always permit the flow of battery current in the discharge direction.

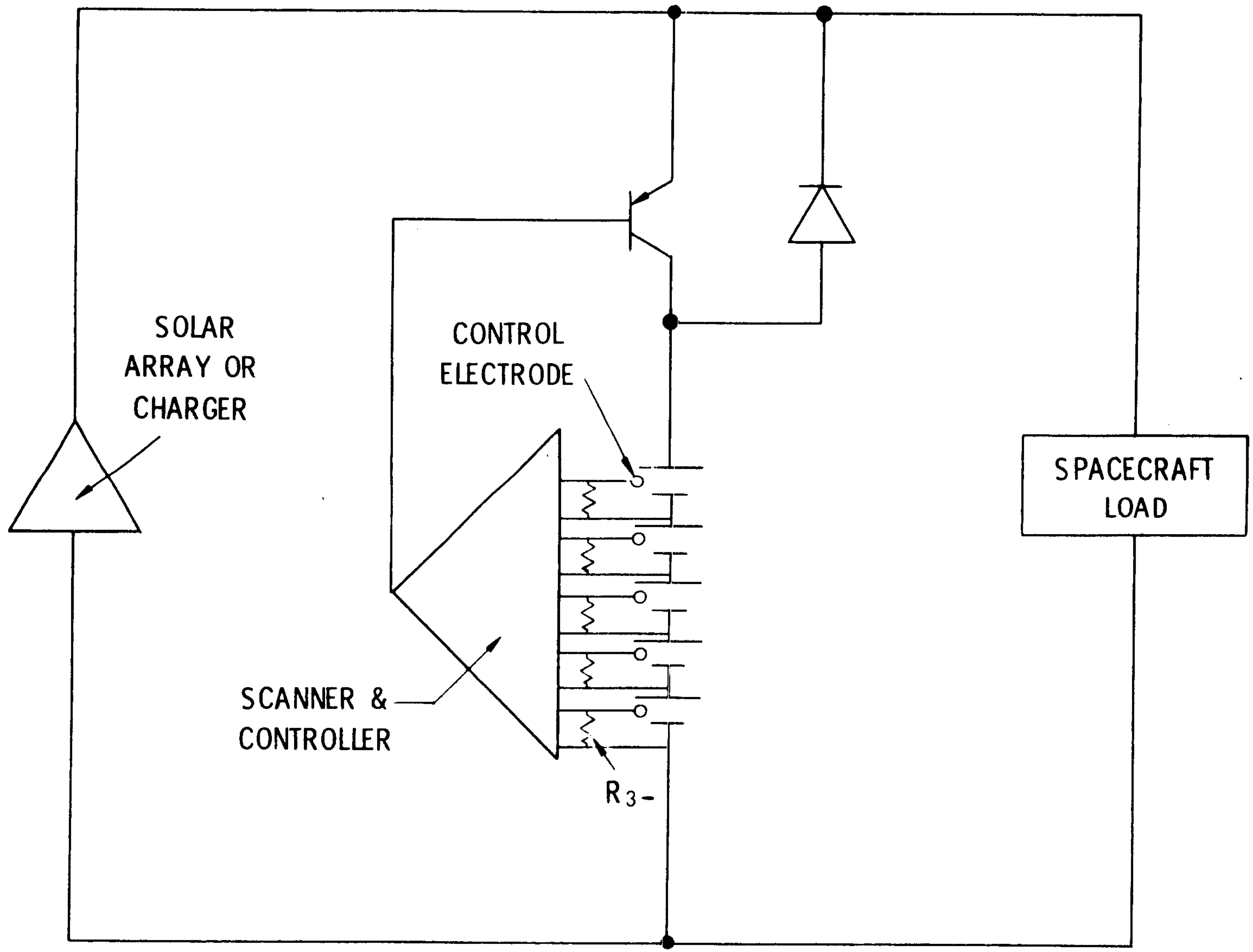

Figure 1. Series Auxiliary Electrode Control Circuit

FUNCTIONAL EXPLANATION OF SHUNT REGULATOR SYSTEM

Another type of charge control is the two voltage level shunt regulator. This system shown in Figure 2 has just been introduced in GSFC laboratories. This device is basically a shunt voltage regulator with an upper and lower voltage limit level. The sensing system is the same as mentioned for the series current controller. The shunt regulator limits the voltage of the battery at the upper voltage level V_H when the signal of the auxiliary electrodes are below the threshold level. When the threshold level is reached, switching transistor Q_1 is turned on which allows V_L to limit at the lower voltage level (2). This voltage level is slightly above the open circuit voltage as a function of temperature to maintain the charge currents at safe levels.

AUXILIARY ELECTRODE AND CELL VOLTAGE CHARACTERISTICS

Tests were conducted at GSFC on auxiliary electrode cells to determine auxiliary electrode and cell voltage characteristics at temperatures of 0, 25, and 40 degrees centigrade. The data from these tests could then be used to define auxiliary electrode and cell voltage limits of the charge controller. A typical test consisted of operating a 5 cell 6AH auxiliary electrode battery at a 25 percent depth of discharge on a 90 minute cycle. The battery was discharged at 3 amps for 30 minutes followed by a sixty minute charge period. The battery was charged at a constant current rate of 3 amps until the auxiliary electrode reached the selected threshold level. At this time the battery was placed on open circuit voltage for the remainder of the charge period.

An auxiliary electrode resistance of 6.8 ohms was chosen for this test because information obtained from previous tests indicated this to be an optimum

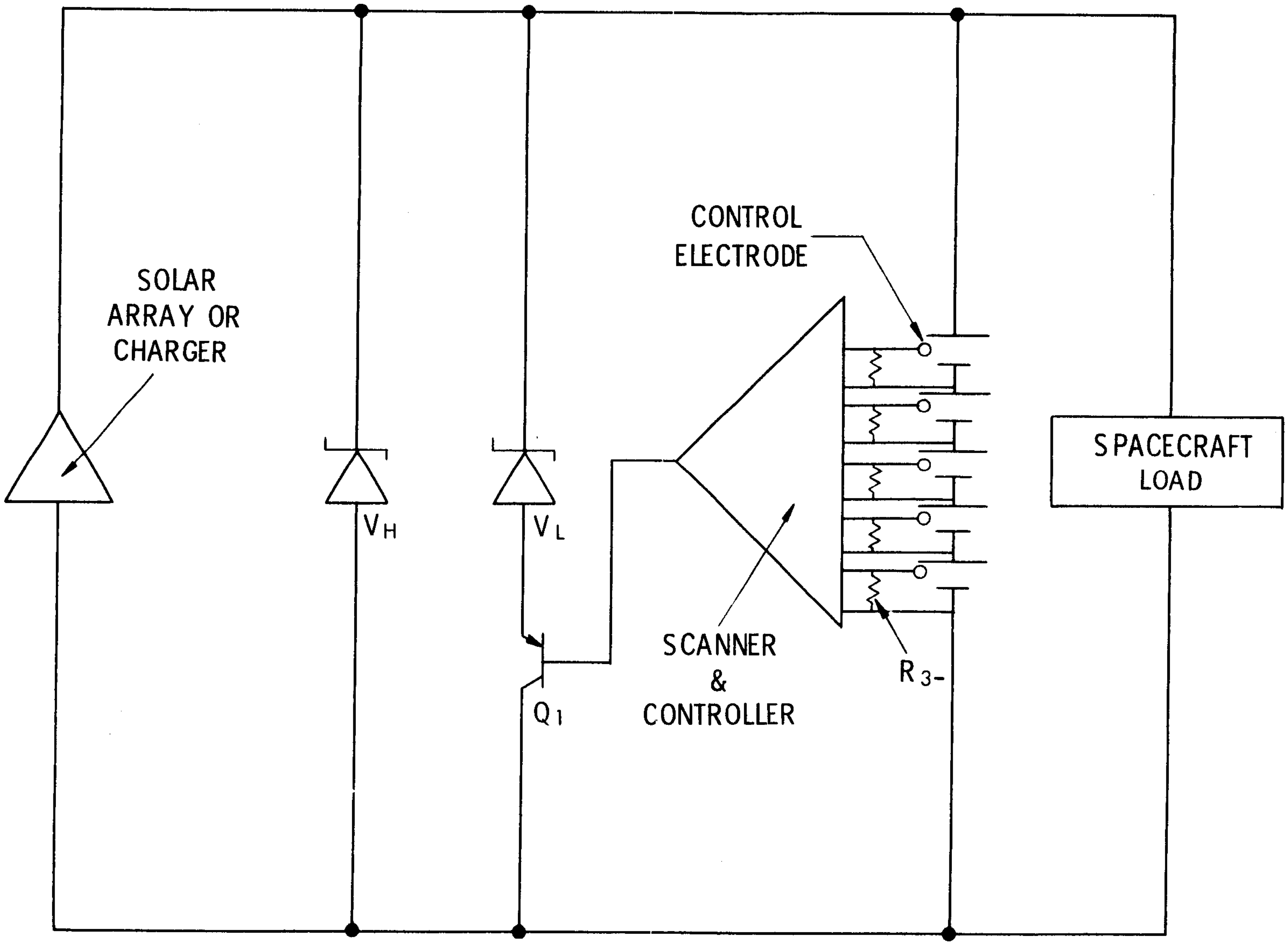

Figure 2. Shunt Auxiliary Electrode Control Circuit

working value. The auxiliary electrode levels at 0, 25, and 40 degrees centigrade were adjusted to give a recharge of 105, 115, and 125 percent respectively. The final adjusted values for the above conditions were 60, 125, and 225 Mv respectively. These values are shown as a function of temperature in Figure 3b and could be used to define the threshold levels of the shunt regulator sensors.

Another method used in maintaining the percent recharge of the battery at 105, 115, and 125 percent for temperatures of 0, 25, and 40 degrees centigrade respectively was to hold the threshold level constant at a given level and vary the auxiliary electrode resistance as a function of temperature. Test data shows that the above conditions are met when for example the threshold level is maintained at a constant value of 125 Mv and the auxiliary electrode resistor values are adjusted to 22, 6.8, and 3.0 ohms at 0, 25, and 40 degrees centigrade respectively. These values are shown as a function of temperature in Figure 3b.

Figure 3a shows the end of charge cell voltage values that occurred at the auxiliary electrode threshold levels. An average end of charge voltage value of 1.54, 1.46, and 1.42 volts was noted at 0, 25, and 40 degrees which decayed to 1.44, 1.40, and 1.37 volts respectively during the open circuit voltage period. These values can be used to define the maximum upper voltage limit and the minimum lower voltage limit for use with the shunt voltage regulator.

OPERATION OF SHUNT VOLTAGE REGULATOR

The shunt voltage regulator (3) consists of a differential amplifier (Q_1, Q_2), amplifier (A_1), and a dumping circuit (Q_3) as shown in Figure 4. For discussion consider a 10 cell nickel-cadmium battery with an upper voltage limit of 14.6 volts (V_H) and a lower voltage limit of 14.0 volts (V_L) at a temperature of 25°C.

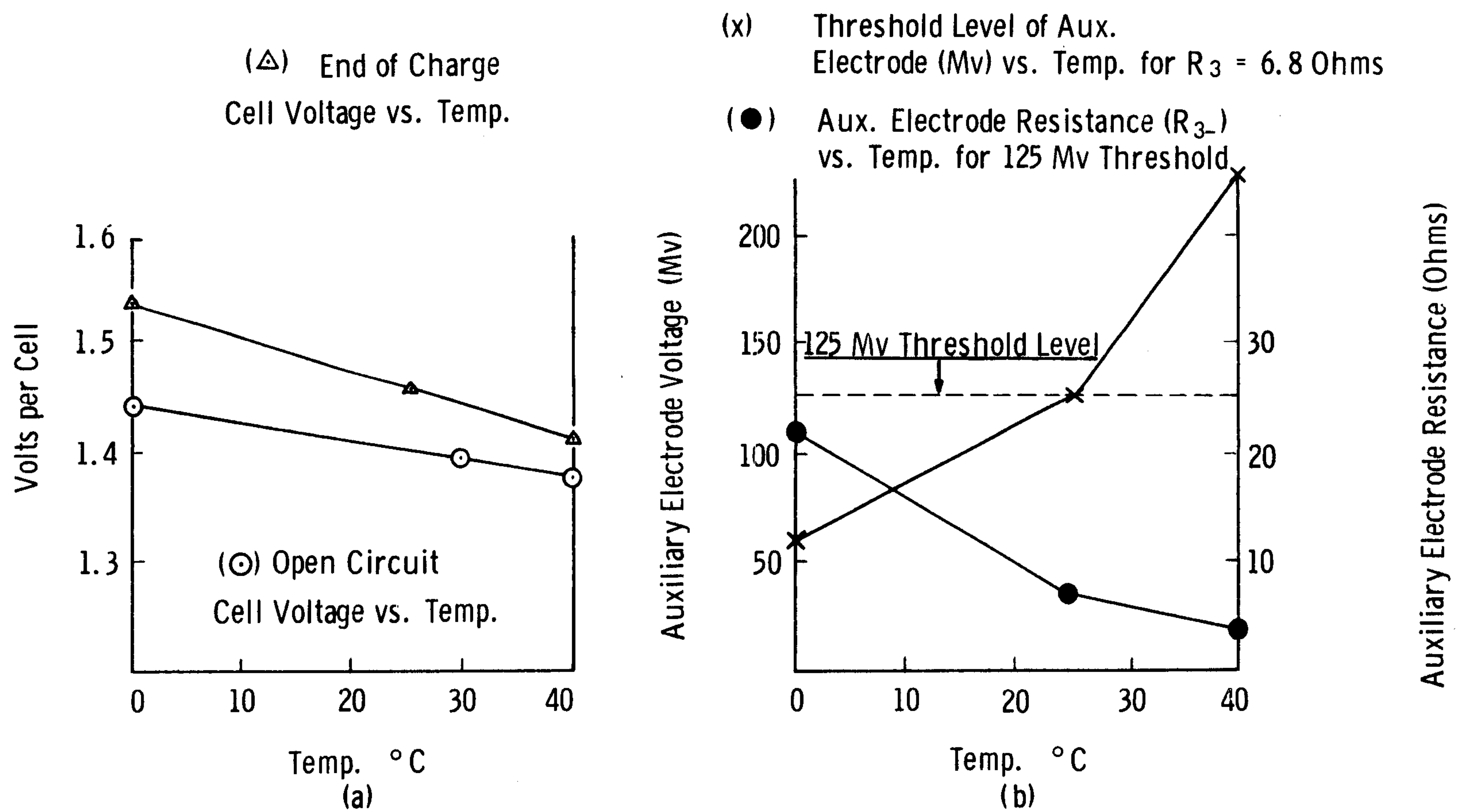

Figure 3. Voltage Characteristics of 6AH Ni-Cd Aux. Elec. Cell

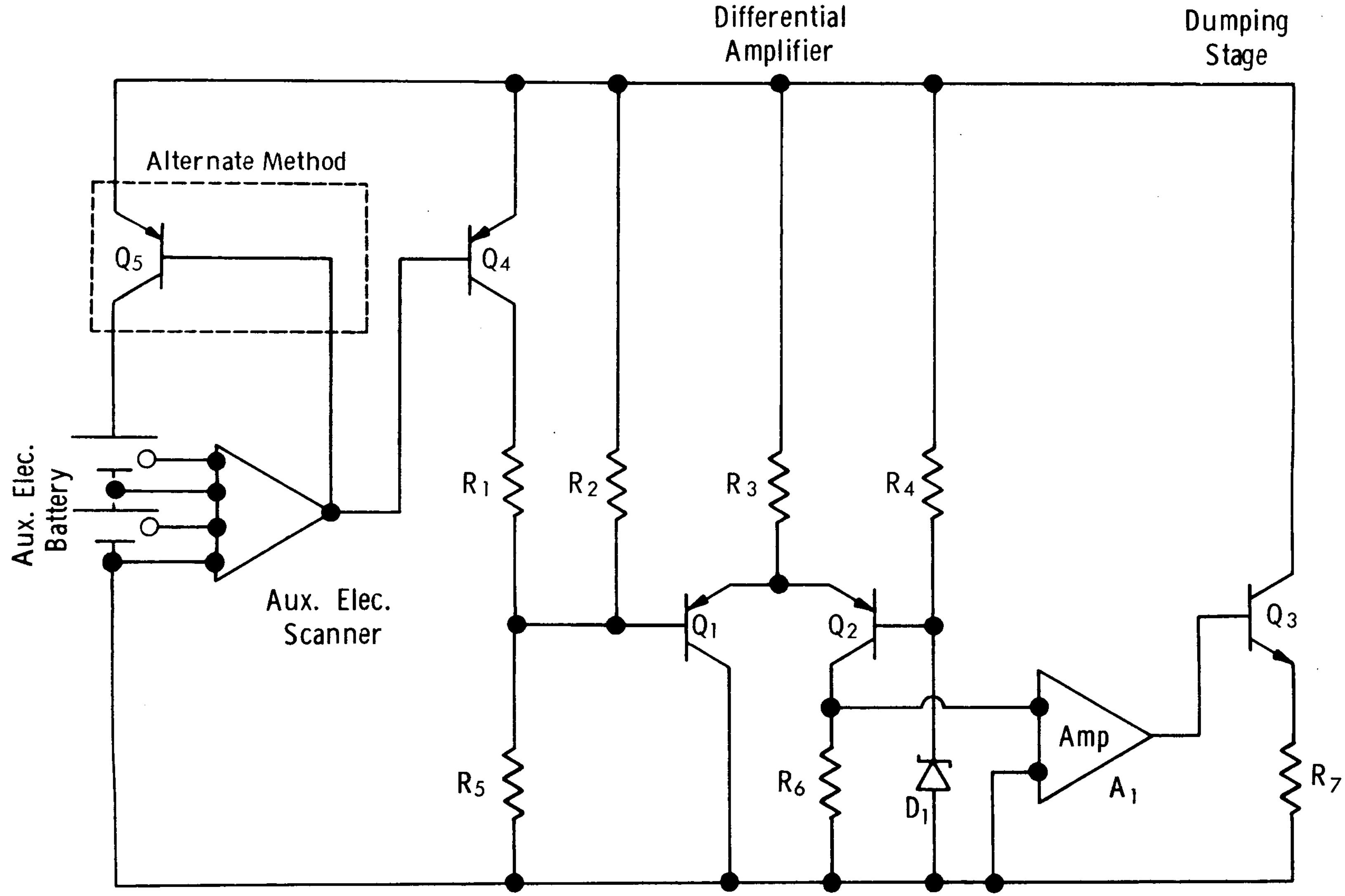

Figure 4. Two Level Voltage Limiter

UPPER VOLTAGE LIMIT

The base of Q_2 is held at +9.0 volts with respect to ground by zener diode D_1. The voltage appearing at the base of Q_1 will be proportional to the battery voltage since the voltage divider resistors R_2 and R_5 are directly across the battery. When the battery voltage is less than 14.6 volts, the voltage appearing at the base of Q_1 will be less than +9.0 volts, causing Q_1 to conduct. Since Q_1 is an emitter follower, the voltage appearing at the emitter will also be less than +9.0 volts. The resultant reverse bias at the base-emitter junction of Q_2 cuts Q_2 off forcing the collector to ground potential. With the absence of a voltage drop across R_6 transistor Q_3 is cut off. Essentially all of the available current from the charger will now flow into the battery. If the battery voltage rises to 14.6 volts, the voltage appearing at the base of Q_1 will have risen above +9.0 volts, which turns Q_1 off and allows Q_2 to conduct (the base-emitter junction of Q_2 is now forward biased). With a voltage appearing across R_6 transistor Q_3 will conduct. Some of the current from the charger will now be directed from the battery and will flow through the dumping transistor Q_3. This reduction of battery current prevents the battery voltage from rising above 14.6 volts.

LOWER VOLTAGE LIMIT

Transistor Q_4 is turned on by the auxiliary electrode scanner anytime an auxiliary electrode voltage of a predetermined level is reached. When Q_4 is turned on R_1 will shunt R_2 which lowers the effective resistance of the upper part of the voltage divider. R_1 is so chosen as to reduce the current dumping point from 14.6 to 14.0 volts.

ALTERNATE METHOD OF REDUCING CHARGE CURRENT TO THE BATTERY

Instead of reducing battery charge current by reducing battery voltage to the lower voltage limit (V_L) a transistor (Q_5) can be inserted in series with the battery. The conductance of this transistor is controlled by the auxiliary electrode signal and can be used to control the current level to the battery.

TEMPERATURE COMPENSATION OF SHUNT REGULATOR

Temperature compensation of the upper voltage level can be achieved by adding a sensistor in series with R_5 which increases resistance with increasing temperature, thus raising the bias voltage of Q_1 causing it to cut off at a lower battery voltage. This sensistor would be located in the battery.

AUXILIARY ELECTRODE SENSOR

The basic auxiliary electrode sensor circuit (4) is shown in Figure 5. One sensor circuit is required for each cell in a battery. The DC outputs of the sensors are connected together through "or" diodes D_{4a}, D_{4b}, ---D_{4n}, thus the voltage appearing at point "x" will be that of the sensor that has the highest output voltage.

Consider a condition where the auxiliary electrode signal is low and below the threshold level of the detector. At this time no current will flow in the DC side of T_1. The 500 cycle positive square wave which is applied to the top of R_7 is divided between R_7 and Z_1. The square wave voltage that appears across Z_1 is filtered and applied to the base of Q_4. This voltage level is sufficient to bias Q_4 in a near saturation condition. As the auxiliary electrode potential increases thus allowing a low DC current to flow through D_6, R_8, and the DC

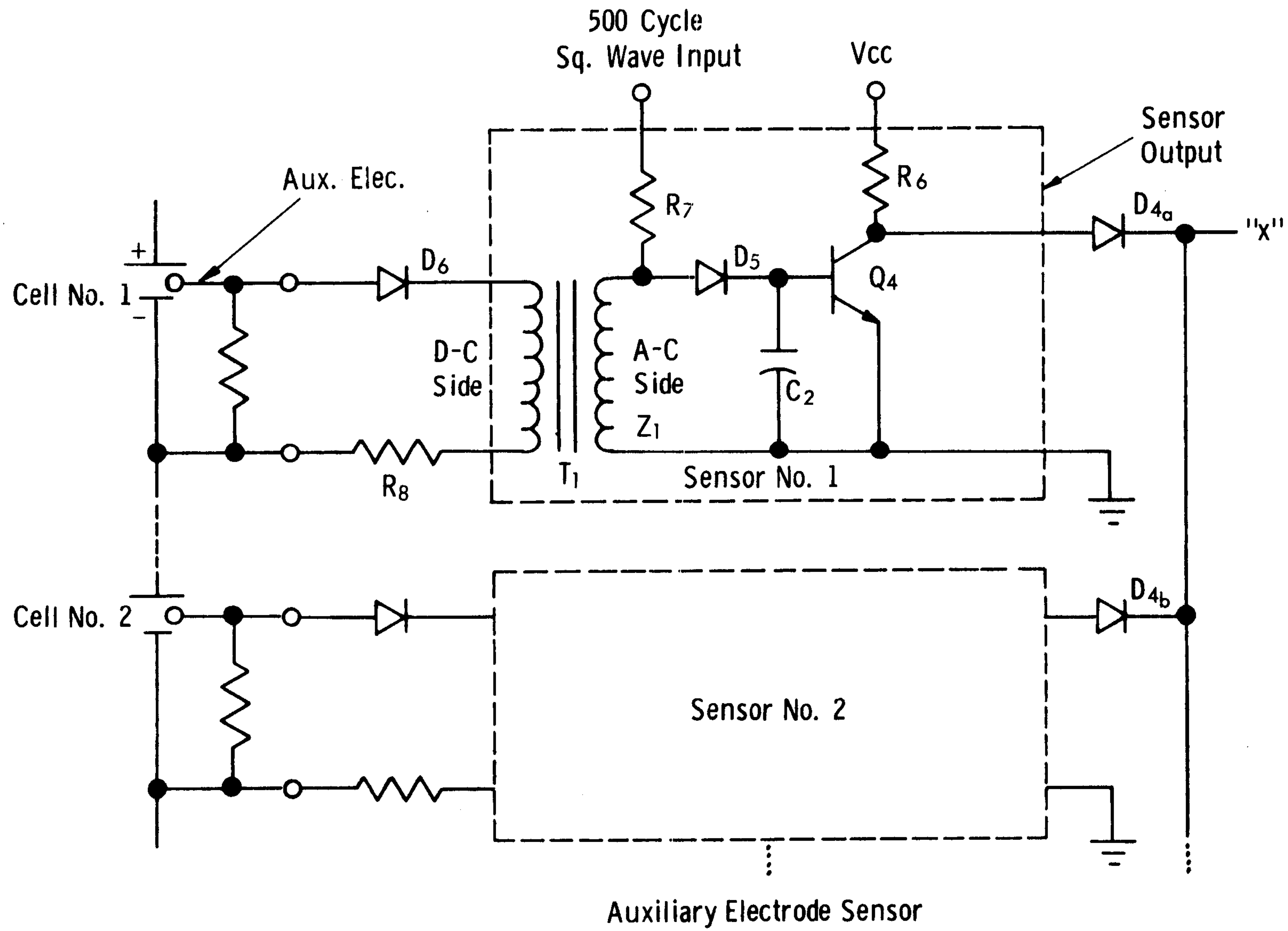

Figure 5. Auxiliary Electrode Sensor

side of T_1 the dynamic impedance of D_6 decreases and is seen as a decreasing reflected impedance in the A.C. side of T_1. The impedance Z_1 is substantially reduced thus changing the voltage divider ratio of R_7 to Z_1. This will lower the voltage drop across Z_1 and consequently the base to emitter voltage of Q_4 causing it to travel through its active region toward cutoff. When Q_4 is near saturation its collector voltage is held at less than 1 volt, but as it moves through the active region toward cutoff, its collector voltage increases from less than a volt toward a maximum voltage determined by the bias supply. With the diodes D_4 of all detectors connected to one point, an "or" connection is formed. The voltage appearing at "x" can be used to control the conductance of the series transistor used in the Series Controller or the transistor used in the Shunt Regulator to reduce its voltage limit level.

BATTERY RECONDITIONER

In addition to the above mentioned instrumentation for auxiliary charge control, a solid state battery reconditioner (5) has been developed to discharge the cells of a battery down to a voltage of 50 Mv or less. The main objective of this device is to restore capacity lost by the "memory effect".

The reconditioner (see Figure 6) continually monitors the voltage of each cell in a battery and the total battery voltage. When the voltage of a battery or of a cell reaches an undervoltage condition the device reacts by placing the battery on a controlled discharge mode. The battery is disconnected from the charger and the load, and a shunt transistor Q_6 is placed across the battery. The conductance of the shunt transistor is controlled by the voltage level of the low capacity cell. When the cell voltage is high the transistor conductance is

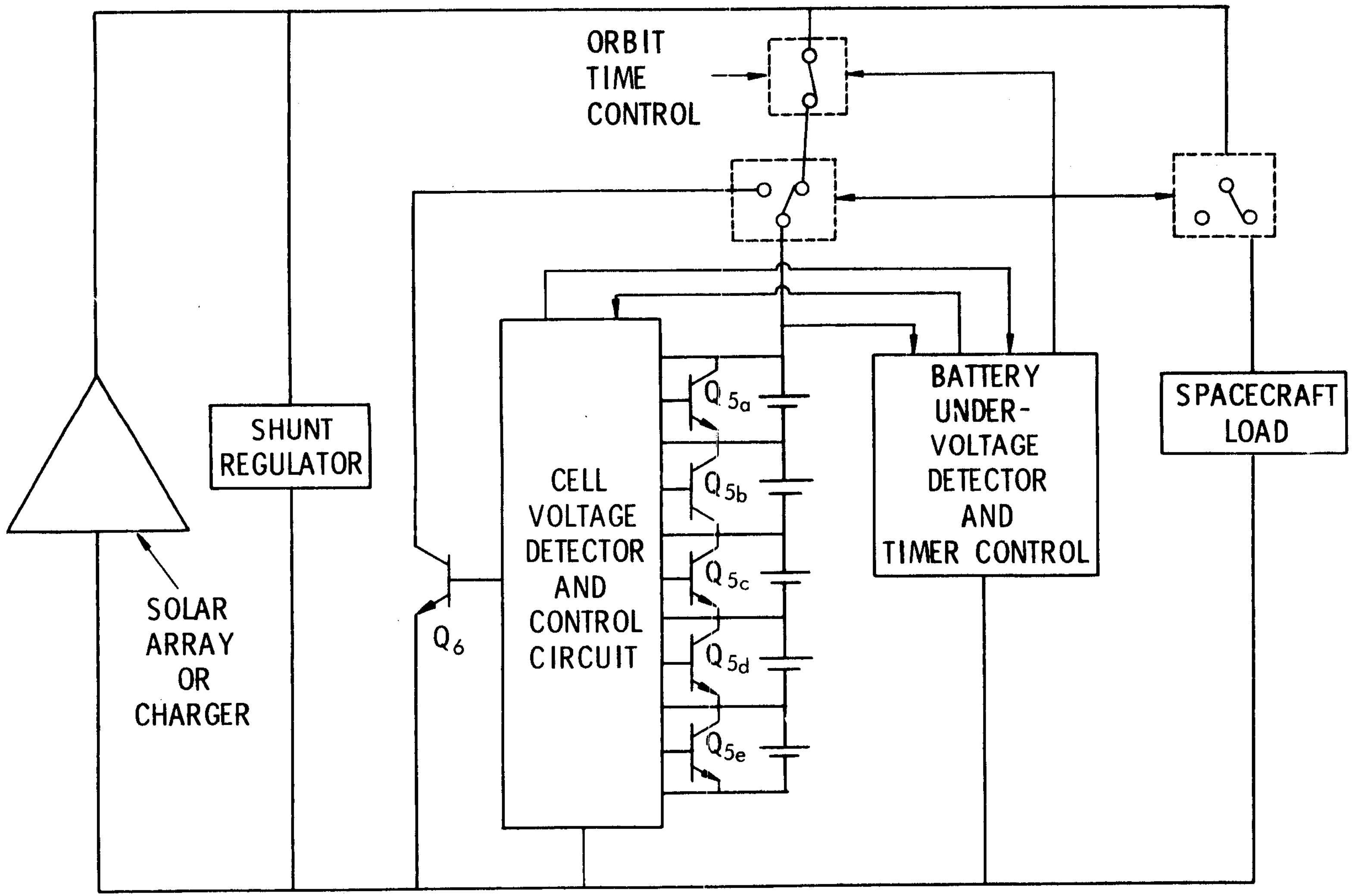

Figure 6. Ni-Cd Batt. Reconditioner System

high. As the cell voltage approaches zero the transistor conductance approaches zero such that the cell could never be reverse charged.

Due to cell capacity unbalance the first cell to reach 50 Mv will cause the conductance of the transistor to go to zero forcing the remaining cells in the battery to stay at a high voltage. To overcome this, a bleed transistor (Q_{5_n}) was placed across the input of each cell sensor and is turned on at a preset current level when the battery goes into undervoltage.

A typical battery reconditioning sequence is illustrated in Figure 7. A low cell voltage condition is noted during normal battery operation at time T = 15 minutes. At this time the battery reconditioner comes into play and reacts by placing the shunt transistor Q_6 across the battery pack. The current through this transistor is noted by the top battery current curve and is designated as I_B. Its conductance is regulated by the lowest cell voltage which comes from cell No. 1. Meanwhile the remaining 3 cells (2, 3, and 4) are discharged down at 500 Ma by transistor Q_5 which is located at the sensor input. The highest capacity cell in this battery is cell No. 4 and it took nearly 75 minutes to discharge it down as compared to 10 minutes for cell No. 1.

SUMMARY

Recent tests at GSFC and N.A.D. Crane show that the auxiliary electrode which first reaches the threshold level during early cycling continues to be the controlling electrode throughout the life of the battery. For reliability it may be sufficient to have 2 or 3 auxiliary electrodes capable of controlling in a 10 cell battery. The remaining cells should have auxiliary electrodes but they should be shorted to the cadmium electrode to insure a low pressure level.

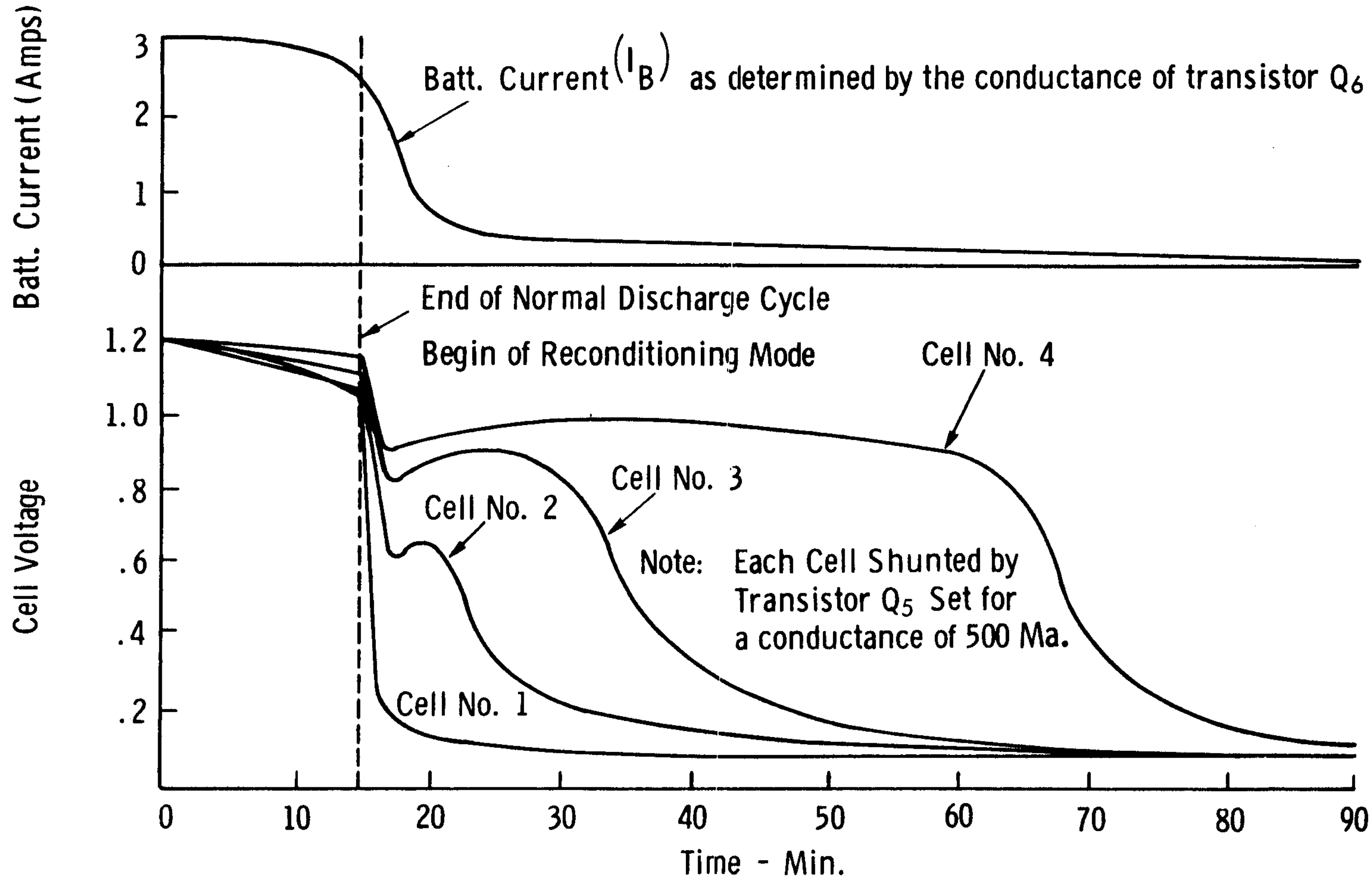

Figure 7. Recondition Sequence of Ni-Cd Cells

Six series charge controllers have been in continuous use for over one year at N.A.D. Crane in the testing of auxiliary electrode batteries. No failures have been reported and no appreciable change in the threshold level of the detectors has been observed.

ACKNOWLEDGEMENTS

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